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Published version deposited in CURVE May 2014

Original citation & hyperlink:

Al-Daraiseh, A. , Shah, N. and El-Qawasmeh, E. (2013) An intelligent energy management system for educational buildings. International Journal of Distributed Sensor Networks, volume 2013 : 209803.

<http://dx.doi.org/10.1155/2013/209803>

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Research Article

An Intelligent Energy Management System for Educational Buildings

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Received 13 April 2013; Revised 6 August 2013; Accepted 21 August 2013

Academic Editor: Ting-Hua Yi

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There is a wide variation in the energy consumption between different educational institutions due to the adoption of different management strategies and different levels of occupants' environmental understanding. The presence of large amounts of information and communication technology (ICT) equipment and heating, ventilation, and air conditioning (HVAC) system causes a major consumption of energy in higher education institution (HEI) buildings. The main objective of this research is to investigate the use of ICT to optimize the energy consumption in HEI buildings and reduce carbon dioxide (CO₂) emission. The first phase of the system has been implemented at King Saud University to measure energy consumption through sensors that read energy consumption of electrical appliances and devices every 10 seconds. The analysis of collected data allows us to develop and employ energy saving strategies that lead to a reduction in total energy consumption. Our preliminary results show that up to 17% of energy consumption can be reduced by simply dealing with standby energy loss of labs' computers. The novelty of this research comes from the use of a functional database approach to deal with high volume of data and query performance and the incorporation of a timetabling system in energy management system.

1. Introduction

Today's world is facing an unprecedented challenge in controlling increasing greenhouse gases emission, which is the main cause of global warming. CO₂ makes 72% of the total emissions of the greenhouse gases [1]. The burning of fossil fuel in order to generate energy for domestic, public, commercial, and industrial use is a major source of CO₂ emission. Any attempt to deal with the issue of global warming requires the reduction of CO₂ emission, which in return requires a reduction in the use of energy generated by fossil fuel.

Climate change and the increase in energy bills are the main driving forces behind a new wave of energy management systems for residential, public, industrial, and commercial buildings. Most of the currently available energy management systems are concerned with real-time energy consumption monitoring and the displaying of energy consumption statistical and real-time data [2–5]. These systems play a crucial role in providing a detailed picture of

energy consumption to occupants and building managers of residential, commercial, and educational buildings. These systems contribute towards influencing the energy consumption behavior of residential building occupants and building managers of commercial and industrial buildings. However, the majority of these systems does not automatically adjust energy usage and leave it to the occupants to respond appropriately to reduce their energy consumption [2–5]. Furthermore, these systems have serious limitations in their integration with HVAC.

The proposed project integrates all energy consumption appliances, machines, and devices into a uniform system using a service oriented architecture (SOA) [6]. This integrated system provides a comprehensive picture of energy consumption and enable the employment of effective energy consumption strategies in a uniform and consistent manner. These energy management strategies range from automatic adjustment of various electrical systems and advice generation for human operator for the use of a human as an actuator.

The system fine-tunes these strategies by learning from past events and their associated actions.

Currently, some energy management systems provide general energy saving tips but do not consider the occupants' energy consumption profiles and the external physical environmental conditions (e.g., external temperature and sunlight, etc.). The proposed project attempts to influence HEI staff, students, and building manager' behavior towards saving energy and taking automatic energy-aware actions to optimize energy consumption while maintaining the quality of work and level of comfort of students and staff.

The process of creating greener higher educational institutions involves efficient use of energy in educational buildings and promoting environmental awareness within students and institutional staff [7]. The proposed project is an effort to make a greener HEI by using ICT based solution to optimize energy consumption and create awareness of green issues and sustainability. The proposed system attempts to address the issue of sustainability and CO₂ emission reduction in HEIs by taking into account occupants' energy consumption profiles and internal as well as external physical conditions. The motivation behind this approach is to provide the staff, students, and building managers with effective advice on their energy consumption, so they can take appropriate actions towards achieving efficient energy consumption in addition to considering automatic energy-aware actions for saving energy, such as the switching off lights or network printers in a laboratory when all computers are already switched off. The fact that the system has to deal with a large volume of sensor data and respond to various queries in an acceptable time is a great challenge. We attempt to deal with this issue using functional database approaches, which allows us to split a higher-level query into low-level queries and then combine their results by applying a service composition approach. Our proposed approach brings together functional database features and a web services composition to deal with the challenge posed by huge volumes of sensor data coming from various sources. The distinguishing feature of the system is that it takes into account the occupancy time of various rooms in the building from a timetabling system. It is believed that this feature will greatly improve the energy consumption of HVAC.

The organization of this paper will be as follows. Section 2 describes the current related work. Section 3 presents the system architecture. Section 4 describes the SOA approach for designing and development of the system. Section 5 provides a description of various components related to management of huge volumes of data and reasoning over that data. Section 6 discusses the implementation of the system. In Section 7 we present the results. Section 8 provides a brief discussion and conclusion of the paper.

2. Current Related Work

Currently, there are a variety of commercial and domestic energy management systems available. Most of them are implemented within what are called building management systems, and the majority of these systems does not include

occupants in the energy management loop. Current energy management systems can be broadly divided into three categories as follows.

- (1) The first category consists of energy monitoring sensors and energy consumption data displays. These are basic systems that read energy consumption and show the consumption on a display. These are more suitable for domestic environment as they depend on human for judgement and actions.
- (2) The second category of these systems is those systems that extend the capability of the first group by allowing alert generation on excessive usage of energy or on some conditions set by the user.
- (3) The third category of energy management systems employs advanced networking and energy monitoring technologies. These systems allow the users to view energy consumption at appliances level and control the appliance usage from anywhere via a web interface.

In the following, we discuss some well-known energy management systems that belong to the third category, as these are the most promising technology for effective energy management.

- (1) AIM (<http://www.ict-aim.eu/home.html>) is a 7th Framework Programme funded project for the design and implementation of a system that aims to minimize energy waste in a domestic environment. In contrast, Digital environmental home energy management system (DEHEMS) uses wireless sensor monitoring network to control home appliances according to user profiles [8].
- (2) Sarnadas et al. proposed an architecture for home energy appliances management and control [9] that focuses on the use of hardware components such as sensors, actuators, and communication network to manage energy consumption in home environment. Another strand of research focuses on providing intelligent interfaces to increase awareness of energy usage and hence influence the householder's behaviour [10, 11].
- (3) There are a number of freely available web based tools for providing householders with common sense advice on their energy consumption (<http://www.google.com/powermeter/about/>, <http://www.microsoft-hohm.com/>, <http://www.imeasure.org.uk/>); however, these tools heavily rely on users' manual input. There are also a number of commercial ICT based energy management systems available (<http://www.plugwise.com/idplugtype-g/home-efficiency>, <https://www.ewgeco.com/>). These tools and systems broadly focus on issues of energy consumption monitoring, displaying, and basic statistical analysis of energy consumption data.
- (4) The goal of the DEHEMS [8] is to empower householders in using their energy consuming appliances

by increasing visibility of energy consumption data and providing intelligent advice on their energy use based on their profiles, and the appliances' profiles.

- (5) Energy surveillance system (ESS). "This system is a web-based energy monitoring system that allows the user to compare energy usage by equipment type, store location, fuel type, or time of day. The web based energy monitoring software allows remote access to the crucial data for energy savings in different locations. The system is built to monitor up to 17 subloads per module within a facility to better detect energy leaks, provide benchmark reports and bill verification, and be alerted when abnormal energy usage occurs" (<http://www.egenergy.com/energy-monitoring#>).

Although some of these systems can be used for energy management in HEIs, they do not provide an effective energy management solution in educational institutions' environment by disregarding timetabling and event-management systems.

There is also an expanding strand of research on HVAC control and occupant behaviour modelling for reducing energy consumption in residential, commercial, and educational buildings. However, their main focus has been on reducing energy consumption while maintaining occupant comfort in terms of maintaining indoor temperature and air quality. The majority of this literature disregards appliances/machine level energy consumption optimization and inclusion, of timetabling and event management systems.

Mamidi et al. proposed an adoptive multiagent system that learns about occupants' behaviour in order to optimize HVAC operation [12]. They use machine learning technique to predict occupancy of the rooms up to an hour in advance to allow HVAC to minimize energy consumption while maintaining occupants' comfort. Their system only deals with temperature control, and they do not give any consideration to energy consumed by PCs and laptops in labs. They also do not include humans in the energy conservation loop.

Hagras et al. proposed an integrated approach using fuzzy logic, neural networks, and genetic algorithm to learn building thermal responses to external weather conditions, internal occupants requirements, and building plants response [13]. Their proposed system works with an existing building management system to reduce the energy demand, but it does not deal with appliance and device level energy consumption and monitoring.

Rogers et al. demonstrate in a simulated environment where a heating agent can optimize heating use to minimize cost and carbon emissions whilst satisfying the home owners comfort requirements [14]. Their simulation shows promising results, but it only considers energy consumption of maintaining home's environmental comfort.

Wang et al. proposed an hierarchical agent based approach to minimize the conflict between occupants' comfort and energy consumption [15]. Their proposed system takes into account management of lighting systems and the built environment temperature without any regard to

appliance level and device level energy monitoring and optimization.

Mo and Mahdavi present an agent based framework for building operators and individual occupants' to negotiate their control activities [16]. Their simulation results suggest that agent-based bilateral control strategy improve occupancy requirements while maintaining optimal energy consumption. Their focus is on temperature and lighting in the built environment.

Yu applied a genetic programming (GP) approach to model occupant behaviour by taking into account variation in occupancy timing [17]. This approach applies GP to learn occupants' behavioural rules and predict the presence of an occupant in a single-person office. It is not suitable for multiple occupancy settings.

Kolokotsa et al. proposed a system that integrates an open architecture and a fuzzy controller, which incorporates thermal comfort, visual comfort, and indoor air quality [18]. The fuzzy controller's structure is adjusted to the users' requirements, which are monitored via a smart card system, and then attempts to optimize energy consumption while maintaining occupants comfort. This system does not address energy consumption at the appliance level.

Figureiredo and Costa have implemented a predictive controller above a data acquisition platform for energy management in buildings [19]. The predictive controller optimises the preferences of the user, which come from several distributed user interfaces while meeting constraints of minimising energy waste.

Timetabling and event-management systems provide rich information for energy management systems. The use of this information can optimize the operation of HVAC in HEIs and appliances level energy consumption. Using this information, the energy management system is able to switch on and off air conditioning and other appliances at a critical time without affecting the comfort of the occupants. It is believed that the proposed system incorporating this information will result in considerable energy saving, as the Kingdom of Saudi Arabia's weather conditions require substantial use of air conditioning. Devices in standby mode waste a considerable amount of energy. Our preliminary results have shown that this hidden energy waste of PC/laptop in computer labs is up to 18% of total energy consumption.

3. System Architecture

In this section, we briefly describe the energy management system's high level architecture as shown in Figure 1. The system is based on a sensor network of energy consumption measuring sensors, occupancy sensors, and temperature and humidity sensors. The Zigbee protocol is used for networking and data exchange. The choice of the Zigbee communication and networking protocol was made so that various Zigbee compliant sensors can be easily incorporated into the network as required. The monitoring system collects data from sensors and sends the data to a data sever via Internet connection.

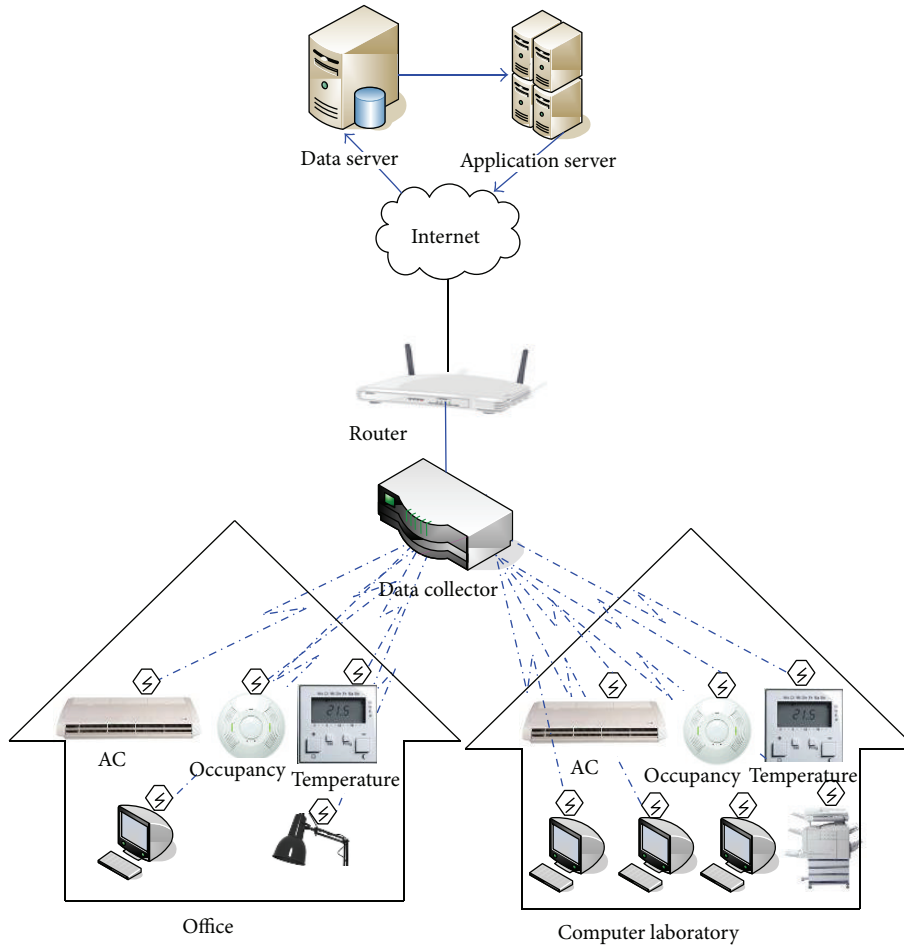


FIGURE 1: System architecture.

3.1. Monitoring Subsystem. Energy consumption and physical environment parameters monitoring functionality is the backbone of our energy management System. It provides essential energy consumption information and parameters to be used by the reasoning subsystems.

The sensors collect energy consumption data of electrical appliances every 10 seconds and send the data to the local data collector, which in turn forwards the data to the central server. Occupancy and temperature sensors are also incorporated into the system in order to detect the presence of people in labs and offices and also room temperature and humidity levels. The real-time collection of data makes it possible to understand the correlation between appliances, statistical analysis, and intelligent advice generation. It also allows building managers to have real-time energy consumption levels for all the equipments and devices.

3.2. Data Storage. The sensor network enables us to monitor the equipments and machines and to create their profiles. The formation of profiles requires initial input from building managers as well, for example, information about various settings of air conditioning. The incoming data from the data collector is stored in a data server. The collected data grows

rapidly. It is resource consuming to extract meaningful information from a database containing raw energy consumption data. In order to reduce response time of queries, the raw data needs to be preprocessed and analyzed to convert it into meaningful information and store it in a collection of analytic databases. The analytic data can be aggregated into a high or abstract level of information about energy usage based on categories such as type of equipment, labs, floor, and period of time.

The long-term storage of data enables the system to use historical data patterns of energy consumption to detect abnormality in energy consumption while incorporating factors such as cold day and hot day. Occupancy data is a main source to identify energy waste due to equipment ON, standby, or idle states.

Having millions of records of energy consumption data coming directly in real time from hundreds of appliances poses a performance problem for data storage, retrieval and reasoning. One of the solutions to data storage and retrieval is TimeSeries DataBlade [20] TimeSeries DataBlade, which has an advantage over traditional relational database management systems "RDBMSs" in its organization and manipulation of time-stamped data. The application of TimeSeries

DataBlade provides a potential solution to the performance degradation of the reasoning process which results from reasoning over a huge volume of data. Another solution could be the use of Hypertable DBMS [21].

3.3. Application Server. Our proposed system makes intelligent use of monitored energy consumption data collected by the monitoring subsystems. On detection of any abnormality in energy consumption, the system tries to figure out the underlying cause by using available data on energy consumption and device profiles or interacting with building managers to get the required information. The application server hosts the proposed intelligent energy management system. We use Glassfish (<http://glassfish.java.net/>) open source application server, which uses Jess Expert Shell [22] as a library to support the reasoning capabilities of the system.

3.4. Rule Base. The intelligent energy management system will be populated with rules prepared with the help of the building manager's knowledge and energy consumption optimization knowledge available in the literature. These rules contain experiential knowledge about energy saving in educational institutions and commercial buildings.

In order to be able to incorporate a new rule, a user interface is provided for the building manager to set values of various parameters and the consequences of such values. This information will then be translated by the system into rules and templates and will be added to the rule base. On the addition of a new rule, the system checks if any inconsistency occurs. If so, the system will try to reconcile amongst rules by interacting with the building manager and making suggestions. The rule base system is modelled using a well-known heuristic classification approach [23]. A typical rule for diagnosing abnormal consumption of energy by air conditioning of a room is shown in Figure 2. The intelligent system discovers the abnormal consumption based on historical data and tries to establish the underlying cause of this abnormality.

3.5. Knowledge Base. The knowledge base encodes knowledge about pieces of advices and their semantics. This knowledge is used as facts by the Jess expert shell. We classify energy consumption activities related to various electrical appliances in home environment [24] into a hierarchy, which will be extended to incorporate new concepts and relations that exist in the HEI domain. The ontological representation as a hierarchy provides the semantics to these activities and provides a rich structure for reasoning rules. This classification also links the pieces of advice with their associated activities. These energy consumption activities are distinct in a way that they are uniquely associated with various appliances.

4. Service Oriented Architecture (SOA)

The development of the system is driven by SOA. SOA is a paradigm that allows software developers to focus on the fulfillment of required enterprise functionalities at a conceptual level by providing standardized communication

protocols, interfaces, workflows, and service management. SOA enables developers to compose the existing service without being concerned with any barriers caused by heterogeneous operating and hardware systems.

The key property of SOA is that it allows services to publish their interfaces and related information, so they become searchable and can be discovered over the Internet. Those services having been discovered and selected can be composed in a certain way to provide certain functions that meet specific application requirements [25]. The rationale for using the SOA approach in design, development, and deployment of the system is to provide standard interfaces for services to be used by other systems.

5. Handling Large Volumes of Sensor Data

We attempt to address the challenge of storing and querying huge volumes of data through functional data services that could compose answers to various energy consumption queries while satisfying the real-time requirement. The proposed architecture of functional data service is shown in Figure 3. Our proposed approach uses a large number of web services with different functionalities to access, handle, and retrieve information over a semantic functional database. The functional characteristic is provided by the fact that the query language is a functional language and the semantic characteristic is offered by the semantic dictionary that describes the structure of the data in terms of types and properties.

The collection of web services (WS) facilitates access to the information as well as the description of the information. This approach enables various high level functionalities. This component offers access to the information for individual users and for other applications as well as providing the connection between an existing relational database (RDB) and a functional database that is built based on the RDB's data. Subsets from the RDB data are transferred into functional data sets. The data subsets represent the most frequently used data and provide the basis for the structure of the functional database. The relational database is accessed only if the necessary information cannot be found in the functional database. The data retrieved from the relational database is then stored in the functional database.

Our proposed approach is to limit the use of relational databases by offering a functional database. Functional datasets contain data from the relational database with semantic annotations. Initially, the functional database contains only a few semantically described datasets, which may not answer all the necessary queries. In this case, a query to the system tries to gather the data from the functional database and takes from there all the information that has been found; the rest of the data that could not be found in the functional database would be searched for in the relational database. The new gathered data is tested to see if it will fit a specific dataset or, in the contrary case, will be used to describe a new dataset. The new datasets will be used later on in other queries. All the datasets in this model have a semantic description of the data that they contain. This means that

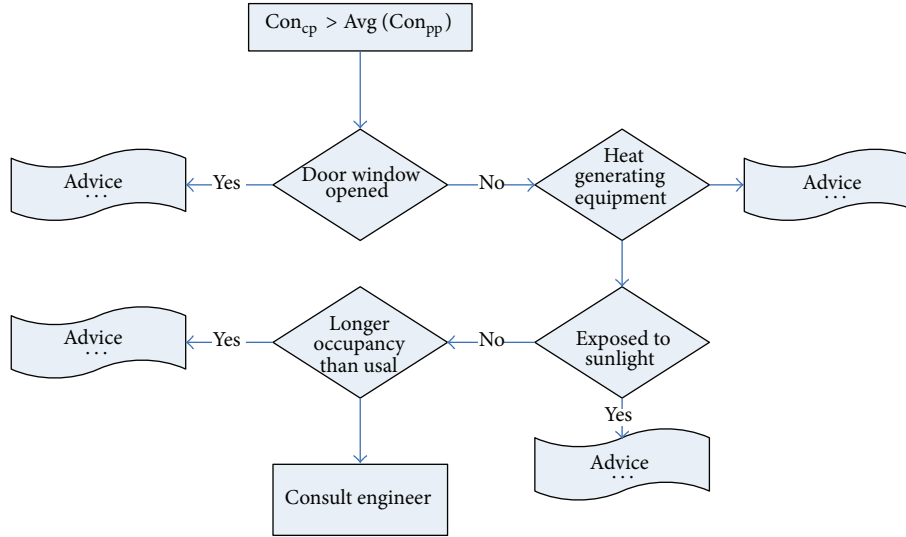


FIGURE 2: Rule for diagnosing air conditioning abnormal consumption.

the functional database is initially smaller and will expand as necessary. Each WS has a specific functionality and can be triggered by different user requests.

5.1. Management System. The management system component is a collection of web services (WS), which facilitate the access to the information as well as the description of the information. This component provides various high level functionalities and offers access to the information for individual users and for other applications. It also provides connection between an existing relational database (RDB)/Hypertable and a functional database that is built based on the RDB's/Hypertable data. From the RDB, data subsets are transferred into functional datasets. The data subsets represent the most frequently used data and provide a base for the structure of the functional database. The relational database is accessed only if the necessary information cannot be found in the functional database. The data that was retrieved from the relational database is then stored in the functional database. This component handles the external requests, forwards specific tasks to the reasoning component, connects the system to an adjacent RDB and provides the responses to the external requests, such as requests for energy consumption data of last summer or last one year.

5.2. Reasoning Component. The reasoning component operates over the datasets that form the functional database. This component represents the part of the system concerned with the logic and reasoning. Furthermore, this component queries the functional database, checks conditions, and transforms data. The reasoning component consists of multiple functions with different functionalities over the datasets. These functionalities form a set of functions. The reasoning component has a functional engine, a resource description framework (RDF) reasoning component which also provides access to a RDF query language.

These functions offer access to and manipulation of data from the database. This component provides the functional layer of the database and the logic of the system. It acts as a bridge between the user's access provider component and the functional database.

Operations over the functional database such as find, update and delete are performed by this component. The functions from this set are passed to the functional engine, and the engine makes the connection to the semantic dictionary, from where it retrieves the semantic description of data that need to be queried. The data gathered from the Semantic Dictionary is passed from the functional engine to the RDF reasoning engine. The RDF reasoning engine contains an RDF query language, which is able to query the RDFS and the RDF files of the database for retrieving the necessary information. There are different tools available that can offer the above mentioned functionalities. For example, the functional engine provided by Clojure (<http://clojure.org/>). Furthermore, the RDF reasoning engine can be described by Jena (<http://jena.sourceforge.net/index.html>), which already offers an API for RDF querying.

5.3. Functional Database. The functional database itself is structured semantically into datasets, with each dataset being represented by RDF. Each set contains summarized data, and the description of each set will be represented in the resource description framework schema (RDFS). For example, a table in a relational database which contains all persons that belong to the university with different columns such as name, age, occupations, and address can be divided based on the semantics of the data in different datasets for the functional database as a "Persons" set. A "Persons" set will be defined by an RDF file as a dataset, which will hold all the data structured into objects with the characteristic that all the objects in this data set are a "Person" type. The RDF schema describes that a "Person" type has mandatory characteristics such as "name", "age" and other optional characteristics too. Furthermore we

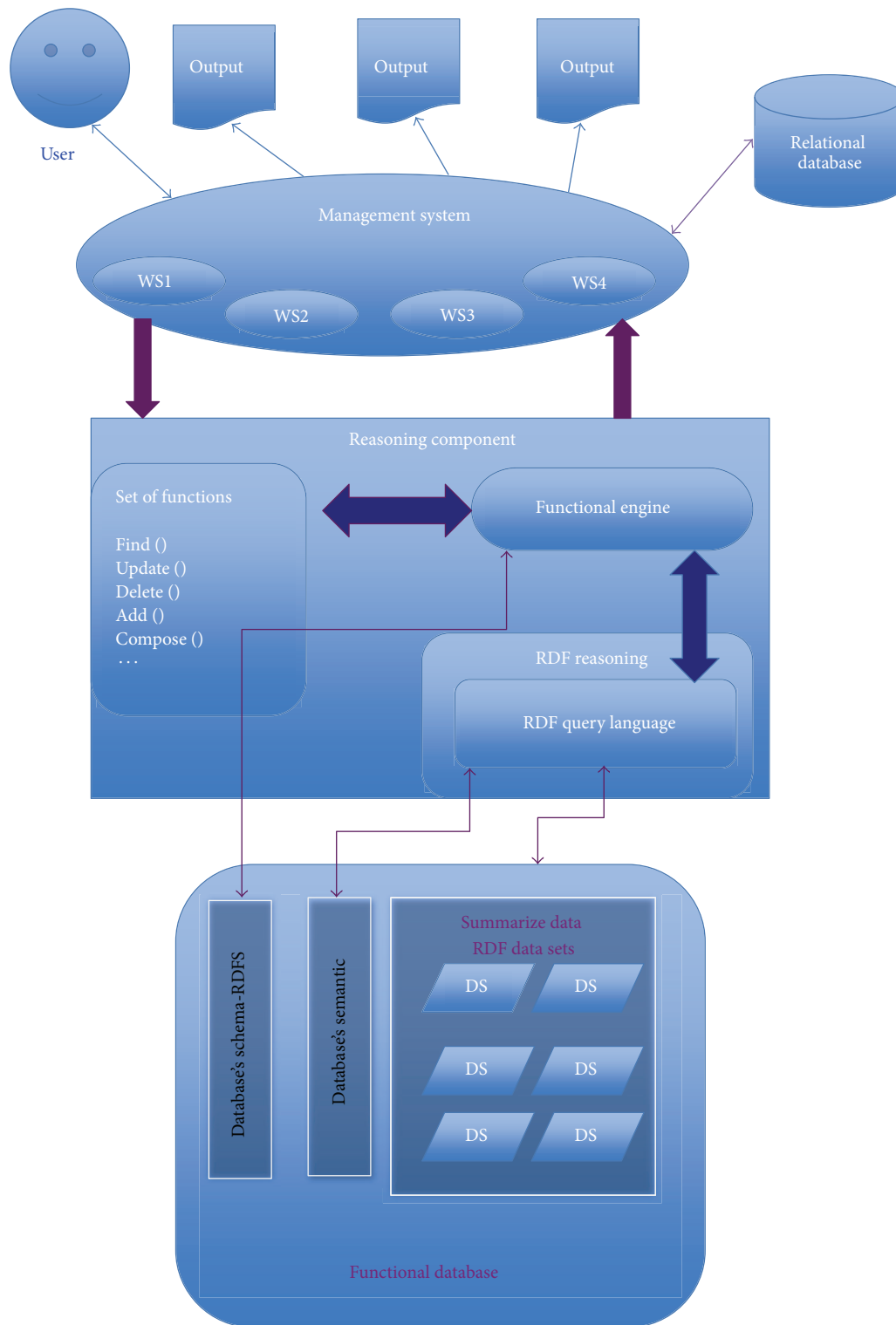


FIGURE 3: Functional data architecture.

can have another dataset, for example, “Staff” which will hold extra information over the “Person” dataset, for those persons from the university database that are employed at the university; each object would add properties which are specific to a “Staff” type (as well described previously in an

RDFS). So, in the “Staff” dataset, we could refer to a specific object from the “Person” dataset adding to it some other staff-specific properties such as employee number and office number. It is a useful approach because many other datasets can be built on the composition of other existing datasets

by adding extra information to it based on the semantic description of that dataset.

The RDFS describes the datasets and their content, from the point of view of what data can be stored inside and the definition of it; and the Semantic Dictionary of the database holds the semantic description of different properties and how they link to each other. As mentioned in previous example, the characteristic “Name” found in a dataset holding the “Person” data type can be semantically described in the dictionary of the database as a composer of “First Name”, “Middle Name” and “Last Name” and then even if other datasets have the “Name” characteristic in a different format, it will be known how to semantically search for the needed data.

The advantage of having functional database encompassing semantic data sets is to provide a smaller search time for reasoning. Multiple functions of the reasoning component can be called by a single WS. The reasoning component handles different functions over the datasets. Each function retrieves the necessary data for reasoning from one or more datasets in order to send back to the web services a proper response. Each function looks for the needed dataset/s in the functional database and composes the information received from them, for example, the composition of the monthly energy consumption data.

6. Implementation

The system adopts web technologies to provide the interfaces for the users to view energy consumption of various appliances/devices and also acts as an actuator in order to take optimal energy consumption actions. We used Protégé (<http://protege.stanford.edu/>) as a tool to create devices/appliances ontology. Currently, we have around 80 concepts relating to electricity appliances/devices defined and around 50 tips regarding energy saving having been encoded. The inference engine, which supports reasoning over knowledge base is Jess expert shell [22]. JessTab (<http://www.ida.liu.se/~her/JessTab/>) was used to integrate Jess and ontology, so the relations between the concepts defined in ontology can be exploited and reasoned.

6.1. Monitoring System. The energy consumption monitoring system has been installed in 10 computer laboratories and 10 offices to collect energy consumption data. A total number of 500 sensors were installed.

The sensors used to monitor and collect the energy usage are Plugwise (<http://www.plugwise.com/idplugtype-g/>) sensors and an electricity clamp meter (<http://www.currentcost.com/products.html>). The Plugwise sensor monitors individual electricity appliance or a collection of appliances, which share the same plug. The clamp meter is attached to the wire of main electricity switch that gathers the total electricity consumption. Both of them make use of radio transmissions to transfer the data to an Internet gateway, which process and send data to a centralized server for other applications to consume. In the following section we describe

the characteristics and component of Plugwise network for energy consumption monitoring.

6.1.1. Plugwise Network. Plugwise is a commercial product that enables measurement of energy consumption of electrical appliances and devices. The energy consumption measuring sensors are called Circles. Plugwise devices that are connected to the ZigBee network are called modules; examples are Circles, Circle+, and Stick. Plugwise is based on the Zigbee 2.4 GHZ wireless mesh network. According to Plugwise configuration, each module can communicate to at least three other modules, and the distance between two modules is limited to 5–10 meters. A configuration file allows the setting of time intervals for energy consumption reading. All Circles within the network are synchronized with a built-in clock of Circle+, which in turn gets synchronized with computer. Plugwise consists of following components.

Circle. The Circle is a plug, which is placed between the wall socket and the plug of an appliance. It measures the energy consumption of the connected appliance and stores the data in its own memory. Energy consumption data is transmitted to the Plugwise software, installed on PC via a wireless Zigbee mesh network. In fact the circle is an energy consumption measuring sensor with an additional functionality of switching off and switching on the appliance attached to it. The Circle gets power from the socket it is plugged into, and the power dissipation of a Circle (node) ranges from 0.55 to 1.1 Watt.

Circle+. It is a Zigbee coordinator. The Circle+ contains additional characteristics within the network, apart from the basic functions of the Circle. It functions as a coordinator in a Plugwise network. It keeps track of the Circles, which are part of the network, and communicates this information to the Stick attached to a computer/data collector. The Circle+ includes a real-time clock and a battery, which synchronizes the time periodically with the other Circles.

Stick. It is also called a main controller. The Stick communicates directly with the Zigbee coordinator also known as the Circle+. The Circle+ communicates with other nodes (Circles) in the mesh network topology.

Source. The Source is the Plugwise software program, which is installed on the PC. The program gives insight into the energy consumption of the connected appliances by means of clear overviews and graphs. The Source also comes with a web server and its own scripting language.

Stretch Lite Pro. Stretch Lite Pro is used to manage multiple Plugwise networks. A single Plugwise network contains at maximum 50 Circles and one Circle+. We have installed multiple Plugwise networks to monitor energy consumption in various labs and offices. Communication with a Plugwise network is done through the Plugwise USB stick, called “Stick”. Each Stick is plugged into a Stretch Lite Pro, which is connected by a UTP cable to the physical network, and

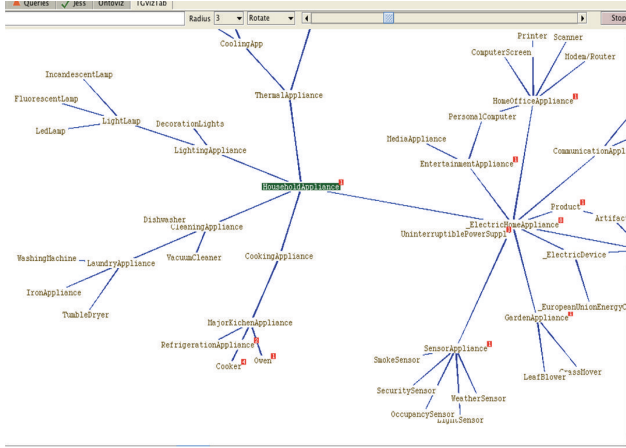


FIGURE 4: Partial view of the ontology hierarchy.

communicates with the controlling PC via the existing LAN communication [26].

6.2. Ontology Implementation. The proposed ontology was first implemented using Protégé ontology development environment; however, later we have adapted it to a standard upper ontology knowledge Interchange Format (SUO-KIF) (<http://suo.ieee.org/SUO/KIF/suo-kif.html>) in order to benefit from the logic rules stored in the original distribution of SUO (<http://suo.ieee.org/>).

The concepts from energy consuming equipment and appliances are organized into a hierarchy based on their functionality rather than their energy consumption. A partial graph of the higher level of the hierarchy is shown in Figure 4.

In developing the energy devices/appliances ontology for HEI domain, we focused on encoding attributes related to the energy efficiency of the devices/appliances to provide a tool for rich knowledge representation for reasoning tools. The aim is to allow systems not only to reason about the energy efficiency of an appliance in short term but also to provide an overview on long-term operational aspects of the device's/appliance's energy consumption.

The best approach to define attributes in SUO is to represent them as a relation. Figure 5 presents the hierarchy for the “annualEnergyConsumption” attribute. The class “BinaryPredicate” represents relations with two parameters—one of them is either a instance or a class while the other is the value that this attribute has for that instance/class. The SingleValueRelation is a relation type where one instance/class can have at most one value assigned. The last class called “PartialValueRelation” represents a relation where not every instance from the relation domain has a value assigned, as opposite to “TotalValuedRelation.”

The first parameter of the “annualEnergyConsumption” relation is declared as a subclass of ElectricDevice, not as an instance. The reason for that is that these kinds of values are calculated for models, rather than individual devices. The second parameter—the value of the relation—is of “EnergyMeasure type”, which has been declared as a constant

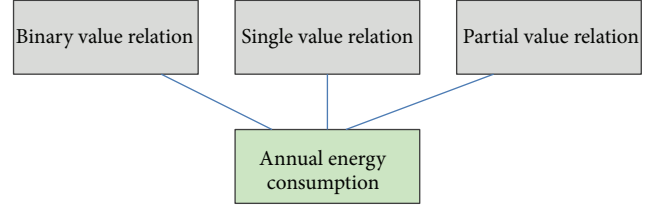


FIGURE 5: Definition of a simple attribute.

quantity, as shown in knowledge interchange format (KIF) (see Box 1).

For illustration purposes, we will describe the hierarchical nature of our developed ontology and explain one electrical appliance/device within this hierarchy. For example Figure 4 shows “Dish Washer” as a lowest level concept which inherits from top level SUO concepts and other defined concepts. Dishwasher has a number of attributes such as brand name, standby wattage, and number of programs, as well as attributes provided by EnergyStar and EU Energy Label (<http://www.energystar.gov/index.cfm?c=home.index/>) programs. Most of the parameters described in both specifications are included for the majority of implemented appliances. There is one additional attribute that tells whether an appliance has an EnergyStar rating or not, which takes an instance of the EnergyStarAttribute as its value (see Box 2).

The conditions that have to be met by an appliance to receive EnergyStar rating vary depending on appliance class and EnergyStar rating version. For example, the EnergyStar 5 requirement for a not compact-sized dishwasher is that its estimated annual energy consumption is lower than 295 kWh. This fact can be defined in KIF as in Box 3.

The older version of EnergyStar required the annual energy usage to be not more than 324 kWh, which is defined in the same style using KIF (see Box 4).

The attributes for the EU Energy Label rating are defined in the same manner.

7. Experimental Results

The system is in operation, and we are collecting the energy consumption data for ten laboratories and ten offices at the moment; more laboratories and appliances will be monitored in the next phase of the project. Offices are not shared and each office is occupied by one faculty, whereas labs are shared among a number of students.

Our focus in this phase is to identify standby energy waste and reduce it by creating awareness among students and staff and by system automated actions. We have installed the sensors and started monitoring the laboratories and offices. In this phase, we monitor the power consumption of desktop computers in labs and offices in addition to lights and other appliances in the offices. Energy consumption monitoring of the labs and offices continued for a period of two months. During the first month energy consumption monitoring was carried out without informing students and staff. The energy consumption for the first month is used as a baseline case in order to assess the effect of energy consumption awareness

```
(subclass EnergyMeasure ConstantQuantity)
(=>
  (and
    (equal (MeasureFn ?NUMBER ?UNIT) ?QUANT)
    (instance ?UNIT UnitOfEnergy))
    (instance ?QUANT EnergyMeasure))
```

Box 1

```
(subclass EnergyStarAttribute RelationalAttribute)
(instance EnergyStar5Rating EnergyStarAttribute)
(instance EnergyStar4Rating EnergyStarAttribute)
```

Box 2

on students and staff. The baseline case is also to be used to assess the impact of energy saving strategies employed by the system. Table 1 shows power consumption and waste due to standby mode during the first month of monitoring. In the second month, students and staff were made aware of the fact that a power consumption monitoring system was installed and how their energy consumption actions can contribute to reduction in energy waste. Table 2 shows the consumption in the second month. The results in Table 2 show a reduction of 8.53% in energy consumption due to the awareness activities that targeted students and staff. They also show that the energy waste is 11.36% down from 20.47% in the first month. Figures 6 and 7 show comparison of energy waste reduction during two months for both labs and offices. These figures indicate a reduction in energy waste as a result of energy consumption awareness and our implemented system.

In the third month, we have enabled the system to take automatic actions to deal with standby losses by detecting and switching off the devices, which are not being used. Simple rules were used to make sure that there is no lab session (according to lab schedule) and that the device consumption is comparable to the baseline waste value for the same device, if so the device is switched off. The trend in one week of monitoring data shows an additional 8.46% reduction in energy consumption due to reducing waste to only 1.45% of the total consumption which was achieved by creating energy consumption awareness and with the help of the energy monitoring system.

The following observations were made based on Tables 1 and 2.

- (1) Employing an awareness program reduced waste energy by almost 50%.
- (2) Using the system to reduce waste brought the waste percentage down to 1.49%.
- (3) The waste in general is very high due to cultural factors in addition to low energy cost in KSA.
- (4) Waste in offices is much higher than that in labs. We believe that the reason is that only one faculty controls the office.

- (5) In offices, the results of the awareness program varied greatly. We believe that the reason is it is hard sometimes to change the use habits of some people.

Currently, we are employing two strategies to lower energy waste: first creating energy consumption awareness among students and staff and secondly incorporating rules in an intelligent system to act as an actuator and automatically to switch off computers and other devices when they go into standby mode.

When the system detects abnormality in energy consumption (e.g., standby), it activates the JESS rule base. The JESS fires an applicable rule which in turn switch off standby appliances. The Plugwise sensors attached to appliance allow switching off and switching on of appliances remotely by receiving message from the software. The reasoning process consults timetabling system event management systems to ensure that the machine/appliance is not scheduled to stay in standby mode.

We display a peripheral message on each login to show the standby power waste to computer users for the last 30 days in order to make all users aware of standby effect on the overall energy consumption. In the next phase, we plan to incorporate more graphics such as a footprint showing the amount of CO₂ generated by the standby energy waste.

Awareness scheme has been used for educational purpose and as an attempt to influence staff and students behaviours towards efficient energy usage. There are lines of research evidence that energy consumption awareness resulted in efficient energy usage [8, 27–29].

Even in absence of occupant awareness the system is able to take automatic actions to reduce energy consumption.

8. Discussion and Conclusion

There are a number of energy management systems available for domestic commercial and industrial environment. Deploying these systems in HEI will not bring the same benefits due to different energy consumption requirements. HEI buildings consist of a large number of classrooms and laboratories, and their allocation is done via timetabling

TABLE 1: Energy consumption of labs and offices during the first month.

Lab/office no.	No. of appliances	Total consumption (KWh)	Waste (KWh)	Waste %
LAB_1	25	859.03	236.93	27.58
LAB_2	25	921.28	252.02	27.36
LAB_3	25	771.13	143.45	18.60
LAB_4	25	637.66	163.79	25.69
LAB_5	25	1078.3	91.29	8.47
LAB_6	30	785.89	118.49	15.08
LAB_7	30	875.71	273.1	31.19
LAB_8	35	1820.34	227.64	12.51
LAB_9	35	1332.99	112.87	8.47
LAB_10	35	1358.85	328.27	24.16
LAB's total	290	10441.18	1947.87	18.66
Office_1	3	93.72	37.44	39.95
Office_2	3	100.78	31.75	31.5
Office_3	3	59.07	32.89	55.68
Office_4	4	74.03	45.63	61.64
Office_5	4	172.37	36.66	21.27
Office_6	4	84.99	43.06	50.66
Office_7	3	99.77	30.03	30.1
Office_8	4	104.98	39.94	38.04
Office_9	3	43.69	34.48	78.91
Office_10	3	49.26	38.19	77.54
Offices' total	34	882.66	370.06	41.93
Total	224	11323.84	2317.92	20.47

TABLE 2: Energy consumption of labs and offices during the second month.

Lab/office no.	No. of appliances	Total consumption (KWh)	Waste (KWh)	Waste %
LAB_1	25	775.14	137.8	17.78
LAB_2	25	819.63	131.89	16.09
LAB_3	25	716.31	78.66	10.98
LAB_4	25	561.1	73.31	13.06
LAB_5	25	1038	43.67	4.21
LAB_6	30	731.99	54.79	7.49
LAB_7	30	767.85	145.63	18.97
LAB_8	35	1720.52	109.67	6.37
LAB_9	35	1288.34	60.1	4.67
LAB_10	35	1228.61	174.36	14.19
LAB's total	290	9647.50	1009.88	10.47
Office_1	3	72.6	12.48	17.19
Office_2	3	88.57	17.32	19.55
Office_3	3	43.89	14.95	34.06
Office_4	4	56.21	24.57	43.71
Office_5	4	147.55	7.33	4.97
Office_6	4	60.7	14.35	23.64
Office_7	3	88.22	16.38	18.57
Office_8	4	76.82	6.66	8.66
Office_9	3	36.96	26.52	71.75
Office_10	3	39.31	26.44	67.26
Offices' total	34	710.84	167	23.5
Total	224	10358.34	1176.88	11.36

```
(=>
  (and
    (instance ?X Dishwasher)
    (not (attribute ?X Compact))
    (attribute ?X EnergyStar5Rating)
    (annualEnergyConsumption ?X (MeasureFn ?ENERGY KilowattHour)))
  (lessThanOrEqualTo ?ENERGY 295))
```

Box 3

```
(=>
  (and
    (instance ?X Dishwasher)
    (not (attribute ?X Compact))
    (attribute ?X EnergyStar4Rating)
    (annualEnergyConsumption ?X (MeasureFn ?ENERGY KilowattHour)))
  (lessThanOrEqualTo ?ENERGY 324))
```

Box 4

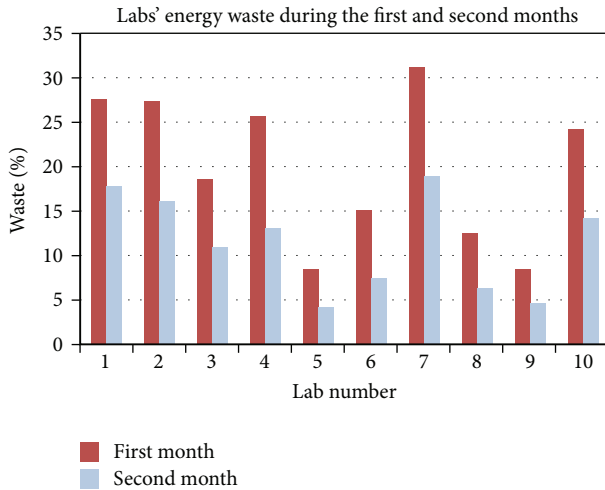


FIGURE 6: Labs' energy waste comparison.

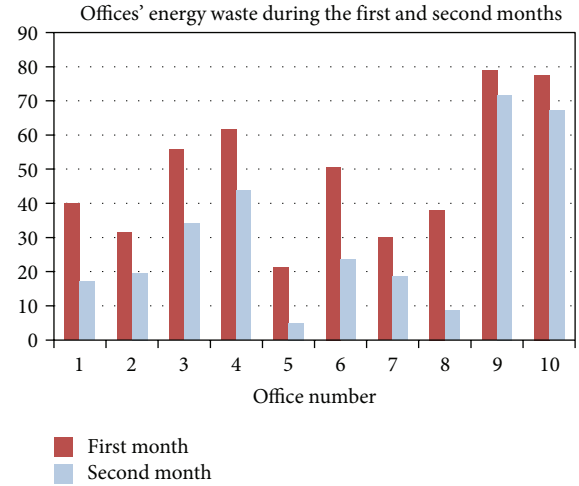


FIGURE 7: Offices' energy waste comparison.

systems. Such occupancy requires an adoptive energy management system that is sensitive to timetabling systems. Event management systems also provide a valuable input for energy management systems to optimise energy consumption. The nature of the building that the system will be employed in has its uniqueness. This is due to the fact that most of the rooms do not have windows. In the absence of windows, people tend to leave lights on when they leave the room. Our preliminary study confirms that energy consumption can be greatly reduced if the deployed energy management system is able to deal with this situation. The proposed system employs state-of-the-art technologies to harvest data from various sources in a seamless way to provide optimal energy consumption in the HEI environment. The next phase of the project will include deployment of energy consumption sensors in more labs and offices. Occupancy sensor and

temperature sensor will also be deployed in order to reduce energy waste of HVAC.

In this paper, we have presented a high level architecture and framework for the development of intelligent energy management system for HEI buildings and also results of the first phase of the project. The proposed system employs a functional data web services approach to provide semantic to data and enable optimal query services by composing services in various ways. One of the distinguishing features of the system is the use of information from timetabling and event management systems. Timetabling and event management systems provide a more accurate picture of occupancy timings, which help the energy management system to schedule HVAC activities in an energy efficient manner. The system also keeps students and staff in the loop and provides them with information on their energy consumption activities in

an attempt to influence their future energy consumption behaviour. Our preliminary study onto energy consumption reveals that the vast majority of equipment stays in the standby mode unnecessarily. In the first phase of the project, the system identifies the hidden energy waste in laboratories and offices and takes appropriate measures to optimise energy consumption.

Using both an awareness program and the developed system, we were able to reduce energy waste down to 14.9% of the total energy used.

Conflict of Interests

All authors are academic, and they do not have financial interest or any other interest in commercial products mentioned in this paper. The commercial products are purely mentioned as a potential candidate for a solution, but the project uses all open sources technologies. The authors do not recommend the use of any commercial products in this paper.

Acknowledgment

The authors would like to thank the National Plan for Sciences and Technology (NPST) at the King Saud University for their support for this Project (no. 11-ENE-1605-02).

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